Conformal Coatings for Reliable Electronic Assemblies

Protective coatings provide a barrier against harsh environmental conditions

Sophisticated electronic circuitry is at the core of hundreds of devices and systems we have come to rely on in our daily lives. Consumer products, such as gaming systems, televisions, phones, GPS devices, and personal computers, keep us informed, entertained, and connected. Energy, surveillance, and defense systems help ensure our comfort, safety, and security. Patient monitoring systems, pacemakers, dialysis machines, and other healthcare products provide critical diagnostic and treatment capabilities to enhance our long-term health and well-being.

Electronics manufacturers go to great lengths to ensure the reliability of their products. In addition to designing circuits and software that satisfy a product's functional requirements, manufacturers devote significant resources to quality assurance activities, including lifetime resiliency testing. For many products in the medical, aerospace, and other industries, long-term reliability is of paramount importance.

Environmental conditions threaten long-term reliability of electronics

Many products are subject to harsh environments in which electronic assemblies are exposed to contaminants, corrosive agents, extreme weather conditions, or mechanical stress. Solar inverters, security cameras, and handheld computers used by field personnel in the transportation and utilities industries are routinely exposed to varying temperatures, humidity, dirt, pollen, and other airborne particles. Aerospace products often undergo rapid compression and decompression in addition to being exposed to airborne contaminants and various weather conditions. Medical electronics products may come into contact with bodily fluids, chemicals, or airborne contaminants. Even consumer electronic devices used in ordinary settings can be exposed to temperature and humidity extremes as well as dust, dirt, and other airborne particles.

Contaminants or corrosive agents, such as chemicals, humidity, dust, dirt, or fungus, in concentrations as low as 10 parts per million (ppm) can damage surface mount (SMT) and other electronic components. A few ions of water vapor can cause electrochemical reactions that lead to corrosion of metal parts in a circuit. “Silver whiskers” can form on the surface of the silver electrical contacts of SMT components, often resulting in short circuits. Additionally, vibration, mechanical shock, and thermomechanical stress can affect the delicate circuit elements that are characteristic of today’s microelectronic devices.

Conformal coatings shield electronics from harmful elements

To protect electronic assemblies, electronics manufacturers often apply a thin, uniform layer of a specially formulated polymer compound to printed circuit boards (PCBs), traces, and components during the last stage of manufacturing. Designed to conform to the contours of the objects to which it is applied, this conformal coating acts as barrier between the electronics and the environment, protecting all areas it covers while strengthening delicate components and traces. Manufacturers often add conformal coatings to electronics even if operating conditions are expected to be benign, as an economical way to enhance reliability.

Conformal coatings commonly consist of an epoxy, silicone, UV curable, or other compound that is formulated to exhibit specific physical, electrical, mechanical, and thermal properties. In order to electrically isolate all conductors on the PCB, conformal coatings are designed to have high...
electrical resistivity. They are resistant to chemicals and moisture and are typically devoid of ionic impurities that may react with moisture. Coatings should also provide good adhesion to PCB and component surfaces, so that any moisture or other contaminant that penetrates the coating has no room to accumulate and cause damage. Because any pinholes that remain in a cured coating can be a source of ingress for contaminants, it is crucial that conformal coatings cure to completion. Ideally, they should be free of solvents, which can be a major source of pinholes.

Coating chemistries offer wide range of properties

Conformal coatings for high-end applications are typically made from epoxy, silicone, or UV curable compounds, each of which offers unique advantages. Easy to apply, epoxy-based coatings generally offer superb protection against moisture, chemicals, solvents, abrasion, and mechanical shock and vibration. Because they are essentially rigid, most epoxy-based coatings are virtually impossible to remove and may stress delicate traces or components when subjected to thermal extremes. Certain grades are specially formulated to be flexible and repairable, at the expense of some chemical and temperature resistance.

The primary advantage of epoxies is their exceptional versatility. They can be formulated to exhibit numerous combinations of thermal, electrical, mechanical, and physical properties to suit a variety of coating applications, with each grade offering a different trade-off of properties. Epoxies operate over a wide range of temperatures, from 4K to 500°F, and can be made to be thermally conductive or insulative, to withstand thermal cycling and thermal shock, to absorb thermal stress, or to have superior dielectric properties. Epoxies exhibit good light stability and are often opaque but can be made clear for opto-electronic applications. Formulators also offer grades that meet specific industry standards, such as NASA low outgassing specifications or USP Class VI biocompatibility tests, and grades that can withstand autoclaving sterilization procedures, as is required for many medical electronics applications.

Most epoxy-based conformal coatings consist of two components that cure at ambient temperatures once mixed and can be cured much faster at elevated temperatures. Many two-part epoxies are available as premixed and frozen compounds, eliminating the need for mixing while offering the convenience of room temperature curing. One-part epoxies require no mixing and typically need heat to cure or to optimize their performance capabilities. Because they tend to run when heat is added, these one-part epoxy coatings are commonly used as glob tops — compounds that encapsulate a chip and its wire bonds — rather than conformal coatings.

UV curable coatings offer excellent environmental protection, extremely rapid processing, and moderate versatility. These easy to use coatings require no mixing and cure within seconds upon exposure to UV light. To cure any shadowed out areas, the use of a dual UV/heat curable compound is required. Although not repairable, UV curable coatings offer outstanding electrical properties, excellent abrasion resistance, and very good chemical and high-temperature resistance. Specific formulations of UV curable coatings vary in hardness, viscosity, flexibility, thermal shock and impact resistance, and other properties.
Silicones offer superior flexibility and high temperature resistance, but are not abrasion resistant and are less resistant to chemicals and moisture than epoxies, especially at high temperatures. Their flexibility allows for thicker conformal coatings, making silicones ideal for applications that require vibration dampening. Silicone-based coatings are easy to apply and can be removed by cutting when rework is required. They can be formulated to be optically clear or to exhibit lower outgassing. Formulators can also control their viscosity and resistance to vibration, shock, heat, humidity, and corrosion. No mix one part silicones cure at room temperature via moisture in the air, while two part systems cure at ambient or elevated temperatures upon addition of a curing agent.

Processing options vary by cost, speed, and required skills

Conformal coatings can be applied by dip coating, spray coating, flow coating, or selective coating. Due to variations in process time, capital cost, and labor cost, each technique is best suited for specific production environments. Regardless of the application method used, it is important to start with a clean surface because good wetting and adhesion are critical to ensure superior protection from water vapor and other contaminants.

Dip coating involves submerging a warmed PCB into a tank filled with a warmed liquid conformal coating, removing the board, allowing excess liquid to drip off the board, and then curing the coating. The thickness of the coating is determined by the temperature of the board and the liquid, the rate of withdrawal, the drip time, and the cure temperature. As the coating drips off, the sharp edges of the board or components may become exposed — a problem known as “thin tip coverage.” To resolve this problem, a second dip may be required. Because the coating penetrates all surfaces on both sides of the PCB, including under components, repair is extremely difficult.

Dip coating is fast, ensures an even coating thickness, and incurs the lowest processing costs of any application method for high volume manufacturing of PCBs, except when masking is required. Masking may incur significant costs, since it must be flawlessly applied by highly skilled operators in order to prevent the coating from seeping into masked areas.

Often used in low and medium volume production environments, spray coating is more time consuming and labor intensive than dip coating. A diluted coating is applied in multiple passes by a skilled operator using a spray aerosol or spray gun in a dedicated spray booth. Coating thickness is determined by the temperature of the material, the atomization pressure, and the type of equipment and line speed used. It is difficult to spray coat under components, but this allows for shield masking to be used instead of highly precise barrier masking. Although spray coating has limitations due to 3D shadow effects, it produces better tip and edge coating than dip coating. Coating materials must be of sufficiently low viscosity to be suitable for spray coating.

Brush or flow coating is the least precise conformal coating application method, and is usually reserved for prototypes, low volume production, or repair applications. A low viscosity coating is poured or brushed onto the board and then cured. The coating may not be uniform and may contain bubbles or other defects.

Selective coating, also known as jetting, is a highly automated form of spray coating used for medium to high volume production environments. A low viscosity coating is dispensed via computer-controlled spray valves onto selected areas of the PCB. Because computer software controls the flow rate and viscosity of the coating, the thickness of the coating can be precisely managed. This highly controlled process minimizes the need for masking and eliminates the need for highly skilled operators, but incurs high capital costs and requires programming skills.

Variety of factors dictate selection of conformal coating

Manufacturers wishing to add a protective barrier to electronic assemblies must first decide whether to use a conformal coating or a thicker, more protective potting and encapsulation compound. Conformal coating thicknesses typically range from slightly less than one thousandth of an inch to roughly four thousandths of an inch, while potting and encapsulation compounds can be up to a quarter of an inch thick. Because thicker materials offer superior electrical and environmental protection, potting and encapsulation compounds are often the better solution, but for designs that have weight or space limitations, thinner, lighter conformal coatings are the appropriate choice.
Selecting a suitable conformal coating begins with an assessment of the primary application need. If stress relief or thermal stability is critically important, for example, a silicone coating is often the optimal choice, whereas a vital need for abrasion resistance eliminates silicones from consideration. When chemical or abrasion resistance is the top priority, a rigid epoxy-based coating is usually recommended.

The specific environment to which the assembly will be exposed is the next consideration. The types of contaminants, severity and duration of contact, heat, humidity, degree of mechanical stress, shock, and vibration are important considerations that dictate the ideal combination of coating properties. The physical and electrical characteristics of the assembly, such as trace thickness and voltage range, are also important to consider. If thermal stress is an issue, then the thermal expansion characteristics of the coating will be important. Processing and cost considerations, such as reworkability, application time, cure time, capital and labor costs, are also important factors in the selection of a conformal coating. For instance, UV curable coatings are often favored when processing speed is of paramount importance — as long as limited chemical and temperature resistance are acceptable.

Specialized applications may require additional performance properties. For high voltage applications, high dielectric strength is important in order to prevent electrical breakdown of the coating. Flame retardant materials that resist ignition or minimize the spreading of flames may be required for applications subject to extremely high temperatures. Although flame retardant conformal coatings are available, such high-risk applications are often better served by more protective flame retardant encapsulants. Flexible coatings that can bend without cracking or delaminating are very important when there is a thermal mismatch between the coating and the board or components, so any thermal stress induced during temperature cycling can be absorbed by the coating material. Such flexibility is especially important in today’s miniaturized circuits, with tiny components and fragile leads.

Conformal coatings significantly enhance the reliability and longevity of electronic printed circuit boards. They protect high performing electronics from environmental conditions that can interfere with circuit performance and cause premature failure. A variety of conformal coating compounds and processing techniques offers a wealth of choices to manufacturers wishing to extend the useful lifetime of their products across multiple industries.

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